^{18}F-FDG PET/CT-imaging of left ventricular assist device infection: a retrospective quantitative intrapatient analysis

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Background. **Despite the use of ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography/computed tomography (PET/CT), diagnosis of a driveline infection in ventricular assist device (LVAD) recipients remains challenging. Our aim was to evaluate the potential of a baseline ^{18}F-FDG PET/CT (prior to an infection) for the diagnosis of an LVAD-related infection.**

Methods. **We retrospectively selected all LVAD recipients who had undergone two consecutive whole-body ^{18}F-FDG PET/CT examinations between January 2010 and December 2016. PET/CT was analyzed qualitatively (uptake pattern) and semi-quantitatively (SUV_{max} and ΔSUV_{max}). SUV_{max} was measured and compared in five distinctive volumes of interest along the LVAD driveline. An SUV_{max} threshold was calculated. Final diagnosis was made by clinical examination, microbiological parameters, and molecular imaging.**

Results. **Thirty patients were enrolled (mean age 54 ± 12 years; 26 male). Mean difference in SUV_{max} for all five positions between the first and the second PET/CT along the driveline was significantly higher in patients with an LVAD-related infection (mean $\Delta SUV_{max} = 4.38 \pm 1.44$) compared to those without a driveline infection (mean $\Delta SUV_{max} = 0.03 \pm 0.43$), $P < 0.05$. Applying ROC analysis, an SUV_{max} threshold of 3.88 resulted in a sensitivity and specificity of 100%, respectively. There were three distinctive uptake patterns in patients with a driveline infection.**

Conclusion. **PET/CT diagnosis in the context of an LVAD-related infection can be improved by comparison to a baseline examination using a distinctive SUV_{max} threshold. (J Nucl Cardiol 2018)**

Key Words: PET/CT-imaging • Molecular imaging • Inflammation

Abbreviations

^{18}F-FDG	^{18}F-fluorodeoxyglucose
LVAD	Left ventricular assist device
PET/CT	Positron emission tomography/computed tomography
SUV	Standardized uptake value
VOI	Volumes of interest

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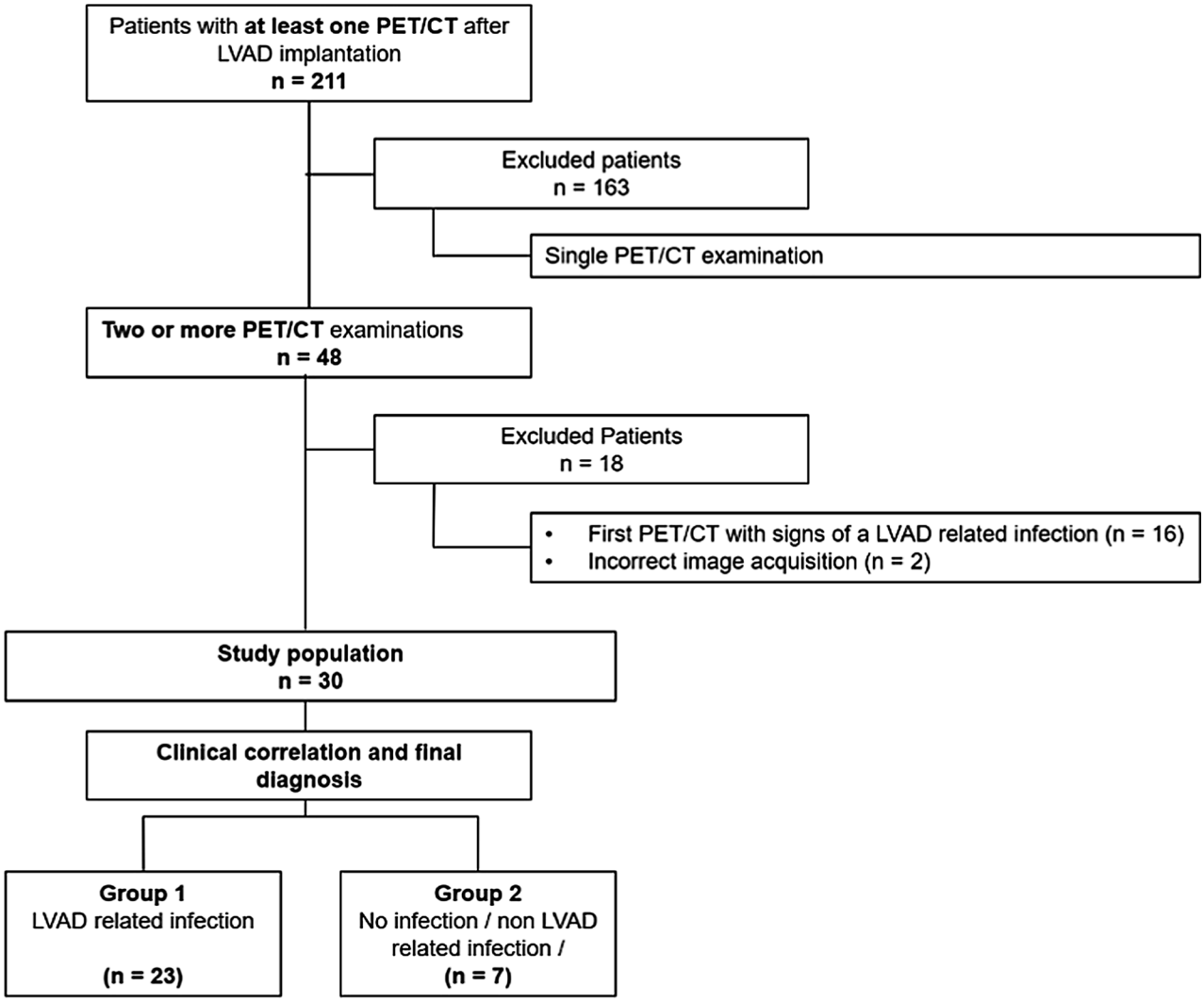

Figure 1. Flow chart of patient selection. *PET/CT*, positron emission tomography/computed tomography, *LVAD*, left ventricular assist device.

INTRODUCTION

Left ventricular assist device (LVAD) implantation is a standard treatment for end stage heart failure.[1] It is used either as a bridge to transplant,[2] as a bridge to recovery,[3] or as a destination therapy.[4] However, device infection represents a major and frequently occurring complication, especially in terms of a driveline infection via the percutaneous driveline, connecting the intracorporeal pump with the extracorporeal control unit. With an incidence between 17 and 22% of LVAD recipients, ventricular assist device infection is frequently encountered in post-implantation treatment and may lead to sepsis.[5,6] Despite the use of standardized definitions of infection,[7] diagnosis of a driveline infection remains challenging and no clinical gold standard has yet been established. Timely, correct and complete treatment of a cardiac device infection are of highest importance for patients' prognosis. Delay increases morbidity and mortality.[8]

Frequently used imaging techniques for identification of a driveline infection include computed tomography, which may visualize infiltrative changes and abscess formation[9] and ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography/computed tomography (PET/CT) allowing visualization of metabolism. ^{18}F-FDG PET/CT seems to be the hybrid imaging of choice, although Litzler et al[10] showed the potential of Leukocyte single photon emission computed tomography/computed tomography (SPECT/CT).

Diagnosis, using ^{18}F-FDG PET/CT, rely mainly on general aspects, like a localized increase in ^{18}F-FDG

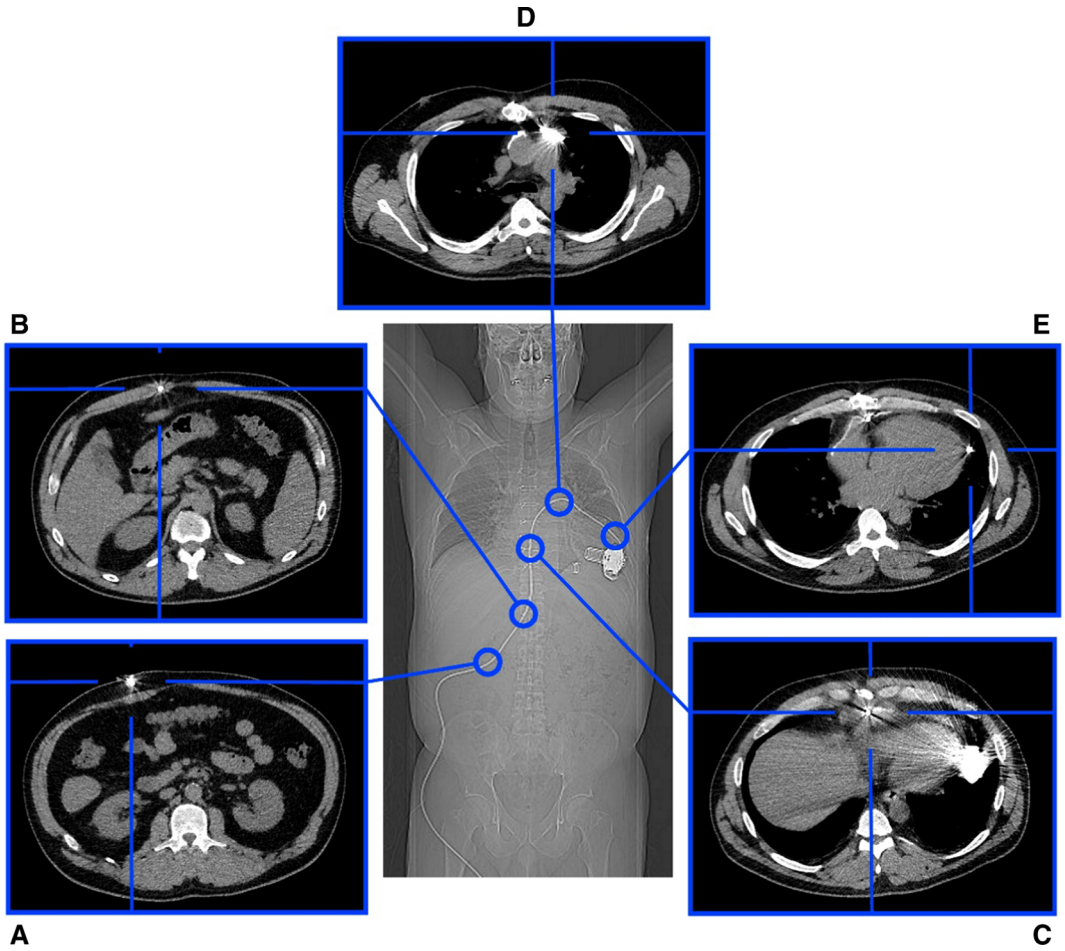

Figure 2. Positioning of the five volumes of interest in a 42-year-old male patient with no LVAD-related infection. (**A**) Driveline exit site. (**B**) Suprafascial driveline. (**C**) Distal subfascial driveline. (**D**) Middle subfascial driveline. (**E**) Proximal subfascial driveline. *LVAD*, left ventricular assist device.

uptake higher than the background activity as used by Dell'Aquila et al[11]. Both Kim et al[12] and Tlili et al[13] each demonstrated LVAD infections using also qualitative analysis only. Sarrazin et al presented the usefulness of ^{18}F-FDG PET/CT in diagnosis of a device infection in a collective of pacemaker and defibrillator recipients, based on a qualitative visual score comparing the area near the device to the lung parenchyma and a semi-quantitative ratio from non-attenuation-corrected images, which was created between the maximum count rate of the device over a mean count rate between normal left and right lung parenchyma.[14]

The aim of this study was to establish an anatomy and morphology-based, reproducible method of semi-quantitative measurement for ^{18}F-FDG PET/CT analysis in LVAD recipients in suspicion of a driveline infection. This measurement is used to retrospectively analyze patients to define a SUV_{max} threshold for improving the PET/CT diagnosis of a driveline infection.

MATERIALS AND METHODS

Study Design and Patient Selection

We identified all adult patients ($n = 211$) with an LVAD system who were admitted to our hospital and who underwent at least two ^{18}F-FDG PET/CT examinations in the time between January 2010 and December 2016 (see flowchart of patient selection, Figure 1). For each of these patients the first ^{18}F-FDG PET/CT after implantation and the first consecutive ^{18}F-FDG PET/CT were selected. All patients with signs of infection in the first ^{18}F-FDG PET/CT examination or clinical suspicion of a driveline infection at the time of the first ^{18}F-FDG PET/CT after LVAD implantation were excluded from this study to ensure no driveline infection was present at the

Table 1. Patients characteristics

	All	Females	Males
Sample size	30	4	26
Age (years)*	54 ± 12 (18–70)	51 ± 9 (43–63)	55 ± 12 (18–70)
Device			
HeartWare	21	4	17
HeartMate II	9	0	9
Medical history			
Ischemic cardiomyopathy	18	3	15
Dilated cardiomyopathy	11	1	10
Unknown cardiomyopathy	1	0	1

*Means ± standard deviations, range

Table 2. SUV_{max} values of patients with an LVAD-related infection in the different measuring positions as indicated in Figure 2

Position	*n*	PET/CT 1 Mean ± SD	PET/CT 2 Mean ± SD	Difference	
				ΔSUV_{max}	*P*
1	23	3.00 ± 1.43	6.54 ± 3.73	3.54	< 0.05
2	23	3.41 ± 0.95	9.28 ± 3.85	5.87	< 0.05
3	19*	4.69 ± 2.00	10.54 ± 7.21	5.85	< 0.05
4	23	4.64 ± 1.35	9.20 ± 5.41	4.56	< 0.05
5	19*	4.72 ± 1.70	6.81 ± 5.71	2.09	0.78
Mean		4.09 ± 1.49	8.47 ± 5.18	4.38 ± 1.44	

*In four patients with a LVAD-related infection only three positions could be measured because of the implanted device (HeartMate II), see Material and Methods. *LVAD*, Left ventricular assist device; *PET/CT*, positron emission tomography/computed tomography

baseline examination. Additionally, two cases could not be worked up because of incorrect image acquisition. The 30 remaining patients with a total of 60 ^{18}F-FDG PET/CT examinations represent the study population. Indication for the first ^{18}F-FDG PET/CT in this population was exclusion of a malignancy in the context of listing for a heart transplantation. Usually this scan is performed prior to a LVAD implantation. Nevertheless, these patients had to be examined after LVAD implantation due to their clinical condition.

The study has been approved by the institutional review board (EK BO/2016-82-RDA-EV). Written informed consent was waived because of the retrospective setting of this study.

^{18}F-FDG PET/CT Acquisition and Analysis

Examinations were performed using a hybrid PET/CT Biograph mCT (Siemens Healthcare, Erlangen, Germany). After a fasting for at least 8 hour, patients received an intravenous injection of 215 ± 41 MBq ^{18}F-FDG for the first examination and 218 ± 49 MBq ^{18}F-FDG for the second examination. Images were obtained 77 ± 19 minutes after injection for the first ^{18}F-FDG PET/CT and 87 ± 23 minutes for the second one, respectively. Simultaneously, a computed tomography (CT) was obtained for attenuation correction and imaging fusion, either as a low-dose CT or as a contrast-enhanced CT, depending on the examinations indication. Oral (mannitol solution, 2%) and iodine-based intravenous contrast media (iomeprol) were administered in patients without contraindication, with a regular dosage of 80 mL intravenous contrast media and 65 mL oral contrast media, respectively. Processing was performed using the Syngo MMWP software (Siemens Healthcare, Erlangen, Germany).

For semi-quantitatively analysis SUV_{max} was measured in five distinctive and reproducible volumes of interest (VOI) along the driveline, drawn by a molecular imaging experienced physician, carefully excluding the myocardium and other neighboring organs with a high metabolism: one around the driveline exit site, one around the proportion of the driveline above the abdominal fascia, and three around the proportion

Table 3. SUV_{max} values of patients without an LVAD-related infection in the different measuring positions as indicated in Figure 2

Position	*n*	PET/CT 1 Mean ± SD	PET/CT 2 Mean ± SD	Difference ΔSUV_{max}	*P*
1	7	2.67 ± 1.07	2.68 ± 0.93	0.01	1.0
2	7	3.47 ± 1.58	3.87 ± 2.00	0.40	0.74
3	4*	4.76 ± 1.25	5.39 ± 1.93	0.63	0.27
4	7	4.13 ± 1.44	3.71 ± 0.80	− 0.42	0.30
5	4*	3.48 ± 0.76	3.02 ± 0.14	− 0.46	0.37
Mean		3.70 ± 0.76	3.73 ± 1.16	0.03 ± 0.43	

*In three patients with a LVAD-related infection only three positions could be measured because of the implanted device (HeartMate II), see Material and Methods. *LVAD*, left ventricular assist device; *PET/CT*, positron emission tomography/computed tomography

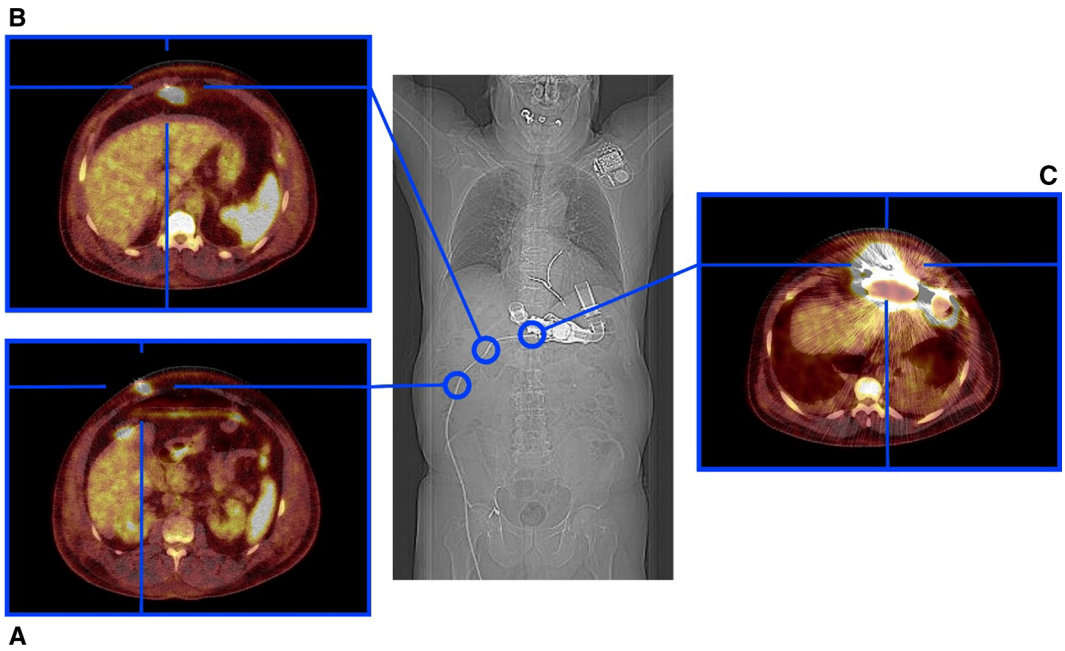

Figure 3. Exemplary case of a 48-year-old male patient with a suprafascial driveline infection. Note: positioning of only three volumes of interest due to implementation of a HeartMate II device. (**A**) Driveline exit site. (**B**) Suprafascial driveline. (**C**) subfascial driveline.

beneath the abdominal fascia. The positioning of the VOI is illustrated in Figure 2.

In most of the cases, all of the above-mentioned five VOI could be drawn, including patients with a HeartWare device (21 of 30), while only three VOI could be drawn in patients with a HeartMate II device due to the shorter subfascial portion of the driveline. The difference in SUV_{max} between the first and the second ^{18}F-FDG PET/CT was calculated for each of the five positions (ΔSUV_{max}). For further analysis, the highest difference was ascertained (highest ΔSUV_{max}).

Additionally, the uptake pattern along the driveline was assessed, including both attenuation-corrected and non-

attenuation-corrected images. Abnormal uptake was defined as a measured activity higher than the background activity.

Clinical Correlation

For clinical correlation and final diagnosis of a driveline infection, all patients were classified at the time of the second ^{18}F-FDG PET/CT by two experienced physicians (JK, PK), applying the working formulation for the standardization of definitions of infections in patients using ventricular assist devices,[3] considering clinical criteria, microbiology and diagnostic imaging, including the ^{8}F-FDG PET/CT. Consensus was reached in all 30 PET/CTs.

Statistical Analysis

SPSS software (version 24; IBM, 2016) was used for all calculations. Shapiro-Wilk test was used to test data on normal distribution. Variance homogeneity was tested using Levene statistics. Comparison of SUV_{max} between the two ^{18}F-FDG PET/CT examinations for the five positions was performed using the paired Student's *t* test for normal-distributed data and Wilcoxon test for non-normal-distributed data. Accordingly, the differences between study groups were tested applying the unpaired Student's *t* test and Mann-Whitney *U* test, respectively. SUV_{max} values obtained from the different measuring locations were analyzed using ANOVA or Kruskal-Wallis test. Correlations were evaluated using Bravais-Pearson correlation coefficient.

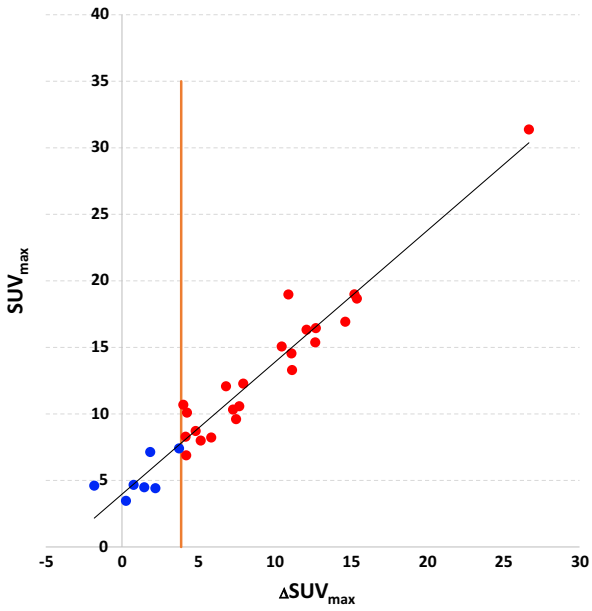

Figure 4. Correlation of SUV_{max} and ΔSUV_{max}. The vertical line represents the cut-off threshold of 3.88 [a.u.]. Individual data have been colored for values smaller than the cut-off threshold (blue) and bigger than the cut-off threshold (red).

For statistical analysis, in patients with a HeartMate II device the only measured subfascial VOI was analyzed and referred to as position number 4.

RESULTS

Study Population

Patient characteristics are found in Table 1. Thirty patients with two consecutive ^{18}F-FDG PET/CT examinations were selected retrospectively. Most patients were male (26 male, 87%). Ischemic cardiomyopathy was the most frequent reason for implantation of the LVAD (60%) followed by dilated cardiomyopathy (37%). There was one case of unknown cardiomyopathy. The two examined devices were the HVAD (HeartWare International, Framingham, MA) in 21 of 30 patients and HeartMate II (Thoratec Corporation, Pleasanton, CA) in 9 of 30 patients.

The time between the first and the second ^{18}F-FDG PET/CT was 541 ± 424 days and the time between implantation and second PET/CT was 691 ± 499 days.

Applying the working formulation of infections in patients using ventricular assist devices,[3] patients were

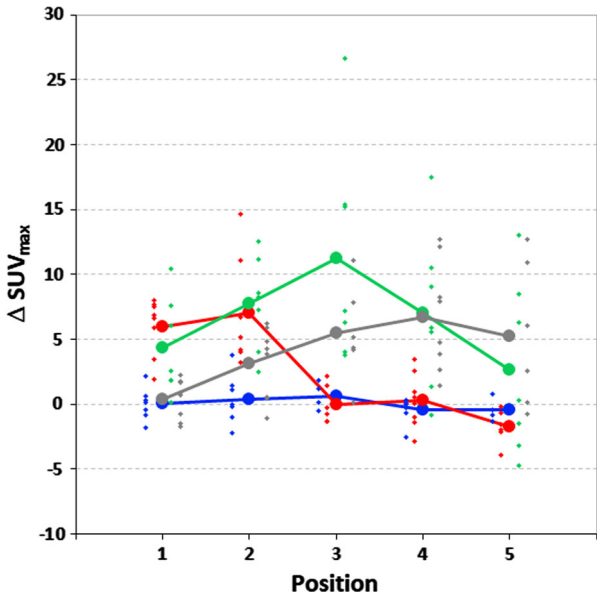

Figure 5. ΔSUV_{max} between the two ^{18}F-FDG PET/CT examinations. Different colors represent the four different ^{18}F-FDG uptake patterns, according to the three subgroups. Patients with a suprafascial infection (red). Patients with a subfascial infection (green). Patients with a percutaneous driveline infection (gray). In comparison Patients with no infection/driveline infection (blue) are displayed. Positions: (1) driveline exit site. (2) suprafascial driveline. (3) distal subfascial driveline. (4) middle subfascial driveline. (5) proximal subfascial driveline.

Table 4. Detailed characteristics of the study population at the time of the second PET/CT

No.	Age, sex	Medical history	Device	Microbiological data	CRP (0–0.5 mg/dL)	LC (4.5–11.0 × 10^9/L)	Interval between first and second PET/CT	Group	Subgroup analysis
1	69 year, M	ICM	HM II	Staphylococcus aureus (BC + DES), Staphylococcus epidermidis (BC + DES)	39.0	8.1	2 mos.	1	Superficial DLI
2	56 year, F	DCM	HM II	Staphylococcus aureus (DES	9.2	8.8	21 mos.	1	Superficial DLI
3	28 year, F	DCM	HM II	Staphylococcus aureus (DES	7.8	7.2	15 mos.	1	Superficial DLI
4	41 year, M	ICM	HW	Fusobacterium spec. (DES), Corynebacterium spec. (DES), Viridans streptococci (DES)	0.8	7.0	29 mos.	1	Superficial DLI
5	48 year, F	DCM	HW	Staphylococcus aureus (DES)	4.5	10.1	14 mos.	1	Superficial DLI
6	69 year, M	ICM	HW	Staphylococcus aureus (DES)	0.3	8.5	3 mos.	1	Superficial DLI
7	61 year, M	ICM	HW	Staphylococcus aureus (DES)	1.3	5.1	7 mos.	1	Superficial DLI
8	60 year, M	ICM	HW	Staphylococcus epidermidis (DES)	2.8	4.8	11 mos.	1	Superficial DLI
9	48 year, M	DCM	HM II	Staphylococcus aureus (BC + DES)	18	26.7	2 mos.	1	Deep DLI
10	66 year, M	ICM	HW	Staphylococcus aureus (DES)	22	18.8	33 mos.	1	Deep DLI
11	61 year, M	ICM	HW	Enterococcus faecalis (BC), Stenotrophomonas maltophilia (DES), Klebsiella pneumoniae (DES)	14	8.6	8 mos.	1	Deep DLI
12	60 year, M	ICM	HW	Staphylococcus aureus (DES)	5.8	14.1	9 mos.	1	Deep DLI
13	43 year, M	ICM	HW	Staphylococcus aureus (DES)	14	7.8	19 mos.	1	Deep DLI
14	50 year, F	ICM	HW	Serratia marcescens (DES)	0.4	4.4	12 mos.	1	Deep DLI
15	60 year, M	DCM	HW	Staphylococcus aureus (DES)	6.4	15.2	4 mos.	1	Deep DLI
16	65 year, M	DCM	HW	Staphylococcus aureus (BC + DES)	17	7.8	6 mos.	1	Percutaneous DLI
17	59 year, M	DCM	HW	Staphylococcus aureus (DES)	3.9	7.5	11 mos.	1	Percutaneous DLI
18	53 year, M	ICM	HW	Staphylococcus epidermidis (DES)	1.7	8.7	61 mos.	1	Percutaneous DLI
19	53 y, M	ICM	HW	Escherichia coli (DES)	21	8.1	41 mos.	1	Percutaneous DLI
20	70 year, M	ICM	HM II	NA	0.12	7.2	23 mos.	1	Percutaneous DLI
21	62 year, M	ICM	HM II	Enterococcus faecalis (DES)	2.8	9.3	20 mos.	1	Percutaneous DLI
22	63 year, F	ICM	HW	Staphylococcus aureus (DES)	12	14.9	3 mos.	1	Percutaneous DLI
23	44 year, M	DCM	HW	Staphylococcus epidermidis (DES), Staphylococcus aureus (BC)	3.5	7.2	27 mos.	1	Percutaneous DLI
24	61 year, M	DCM	HM II	Pseudomonas aeruginosa (DES)	8.3	4.5	20 mos.	2	No DLI

Table 4 continued

No.	Age, sex	Medical history	Device	Microbiological data	CRP (0–0.5 mg/dL)	LC (4.5–11.0 × 10^9/L)	Interval between first and second PET/CT	Group	Subgroup analysis
25	18 year, M	unknown	HW	negative	2.4	8.5	< 1 mo.	2	No DLI
26	43 year, F	ICM	HW	negative	0.46	6.7	29 mos.	2	No DLI
27	44 year, M	DCM	HM II	Enterococcus faecalis (BC)	17	6.9	26 mos.	2	No DLI
28	60 year, M	ICM	HM II	negative	0.23	6	25 mos.	2	No DLI
29	60 year, M	ICM	HW	negative	1.8	8.9	3 mos.	2	No DLI
30	54 y, M	DCM	HW	*Streptococcus oralis* (BC)	4.6	9.3	34 mos.	2	No DLI

PET/CT, positron emission tomography/computed tomography; *CRP*, C-reactive protein; *LC*, leucocyte count; *ICM*, ischemic cardiomyopathy; *DCM*, dilated cardiomyopathy; *HM II*, HeartMate II; *HW*, HeartWare; *BC*, blood culture; *DES*, driveline exit site; *DLI*, driveline infection

classified into the two categories LVAD-related infection ($n = 23$) and no infection/non-LVAD-related infection ($n = 7$), respectively.

SUV_{max} and ΔSUV_{max}

In patients with an LVAD-related infection SUV_{max} was significantly higher in the second ^{18}F-FDG PET/CT examination for positions 1-4 ($P < 0.01$). There was no significant difference in position 5 ($P = 0.78$). Detailed results are shown in Tables 2 and 3. In contrast, no statistically significant difference was observed in patients with no infection/non-LVAD-related infection. An exemplary case of a driveline infection is shown in Figure 3.

The mean difference in SUV_{max} for all five positions between the first and the second ^{18}F-FDG PET/CT along the driveline was significantly higher in patients with an LVAD-related infection (mean $\Delta SUV_{max} = 4.38 \pm 3.69$) compared to those without a driveline infection (mean $\Delta SUV_{max} = 0.02 \pm 0.26$), $P < 0.05$.

In addition, the highest SUV_{max} seen in any of the five positions in the second ^{18}F-FDG PET/CT correlates with the highest ΔSUV_{max} ($r = 0.97$, $P < 0.01$), matching the assumption of an initially low SUV_{max} in the baseline ^{18}F-FDG PET/CT. Figure 4 displays the correlation of the highest SUV_{max} and ΔSUV_{max}. There was no such correlation in patients without an LVAD-related infection.

A receiver operating characteristics (ROC) curve was calculated from the highest ΔSUV_{max} resulting in an area under the curve (AUC) of 1, corresponding to a sensitivity and specificity of 100%, respectively, for a cut-off ΔSUV_{max} value of 3.88. In comparison a ROC curve for the highest SUV_{max} seen in any of the five positions shows an AUC of 0.99, corresponding to a sensitivity of 100% and a specificity of 71%, respectively, for a cut-off SUV_{max} value of 5.78.

^{18}F-FDG Uptake Pattern

Patients with a driveline infection could be further divided into three distinctive groups considering the ^{18}F-FDG uptake, derived from the uncorrected images, the highest SUV_{max} along the driveline and the ΔSUV_{max} between the two ^{18}F-FDG PET/CT examinations: (1) a superficial driveline infection up to the abdominal fascia (suprafascial); (2) a driveline infection spread beyond the abdominal fascia (subfascial); (3) a percutaneous driveline infection, along an additional postoperative abdominal wound, sparing the driveline exit site. Figure 5 displays the ΔSUV_{max} for the three distinctive ^{18}F-FDG uptake patterns in comparison to patients with no sign of infection in the second ^{18}F-FDG PET/CT.

Microbiology and Laboratory Diagnostics

In 22 out of 23 patients with a driveline infection, the driveline exit site was colonized at the time of the second ^{18}F-FDG PET/CT (in one patient no swab was taken). All microorganisms detected through swabs were facultatively pathogenetic and most of them were part of the normal human skin flora. Most frequent germs were *Staphylococcus aureus* (68%) and *Staphylococcus epidermidis* (18%). Only one patient without a driveline infection had a positive swab, with proof of Pseudomonas aeruginosa. Detailed infection-related data are summarized in Table 4.

Five positive blood cultures were taken in 4 patients with a driveline infection, with a positive result for *Staphylococcus aureus* in all 4 cases and *Staphylococcus epidermidis* and *Enterococcus faecalis* in one patient, additionally. With one positive blood culture for *Pseudomonas aeruginosa* and *Enterococcus faecalis*, respectively, there were in total 2 positive blood cultures in the group without a driveline infection.

Statistically, there was no significant difference in infection-related blood tests (C-reactive protein and leucocyte count) between group 1 and group 2 and accordingly between the two ^{18}F-FDG PET/CT examinations.

DISCUSSION

In this retrospective study, we analyzed a particular collective of LVAD recipients who underwent two ^{18}F-FDG PET/CT examinations, first after implantation and without signs of infection, and at a second time, with suspicion of a device infection. Our results of qualitative analysis are comparable with previous work by Kim et al[12] or Dell'Aquila et al[11]. This method of comparing the ^{18}F-FDG uptake along the driveline to the background activity or to a comparable organ like the lung is little prone to artifacts. Though it depends on the examiners experience and it is not as applicable for follow-up and intra- or interpatient comparison.

Semi-quantitate analysis, particularly SUV_{max}, seems to be a valid addition to the use of a qualitative analysis, as SUV_{max} along the driveline is significantly increased in patients with a driveline infection in our study population. Detailed semi-quantitative analysis of the ^{18}F-FDG uptake along the intracorporeal driveline using anatomy-based positions allows to describe precisely the driveline infection pattern for therapy planning and follow-up. Four of the five presented positions along the driveline showed to be reliable while the fifth position seems to be of little significance. This might be due to the high physiological ^{18}F-FDG uptake in the surrounding myocardium, as no preparations for suppression of myocardial ^{18}F-FDG uptake were taken.

Additionally, we were able to identify a diagnostic threshold of an SUV_{max} of 3.88 with a sensitivity and specificity of 100%, respectively, which exceeds the diagnostic value of SUV_{max} measured in a single ^{18}F-FDG PET/CT for driveline infection.

Our work encourages the use of a baseline ^{18}F-FDG PET/CT for intrapatient analysis at a later point of time. The considerable radiation exposure is less noteworthy compared to the high risk of driveline infection in LVAD recipients.

The LVAD recipients examined by Gordon et al developed driveline infection involving the driveline in most cases; however, most infections also involved other sites such as the pump pocket, pump housing, and bloodstream.[5] Besides the isolated infection along the driveline and the infection including other sites of the device, we identified in our study a distinctive third group of percutaneous driveline infections via a postoperative wound. Except for the different entry of the infection, this group seems to have the same pattern of infection and possible spread as the two previously described groups.

However, some limitations are worth mentioning: all semi-quantitative data are PET scanner specific and the given numbers may not be transferrable to other scanner systems or another set-up accurately, requiring obtaining of scanner and set-up specific values.

Our study population consisted of two different LVAD device types, belonging to the second and third generation of LVAD systems currently used. The different implantation methods and individual driveline length required an adaption of our volumes of interest for the semi-quantitative analysis.

The clinical correlation and final diagnosis were based on clinical experience and criteria which were statistically not significant. This is a common problem, as inflammatory markers remain higher in patients after implantation of an LVAD, compared to healthy controls.[15] The strongest evidence for an infection are swabs from the explanted driveline or device, which are seldom available.

Future work should use a comparable method of semi-quantitative analysis for a more precise and comparable approach. Furthermore, the SUV_{max} threshold should be applied to a larger cohort, with focus on the clinical outcome.

NEW KNOWLEDGE GAINED

Facing the question of a left ventricular assist device (LVAD) infection in ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography/computed

tomography (PET/CT) analysis, a baseline examination for comparison without clinical signs of infection can simplify the diagnosis.

Qualitative and semi-quantitative analysis, including SUV_{max}, ΔSUV_{max}, and an SUV_{max} threshold, supports diagnosis of an LVAD infection and allows to determine the extent of infection along the driveline.

There are four distinctive patterns of infection in LVAD recipients. A superficial driveline infection up to the abdominal fascia, a driveline infection spread above the abdominal fascia and a percutaneous driveline infection, along an additional postoperative abdominal wound, sparing the driveline exit site.

CONCLUSION

^{18}F-FDG PET/CT diagnosis in the context of an LVAD-related infection can be improved by comparison to a baseline examination using a distinctive SUV_{max} threshold.

Disclosures

None of the authors have anything to disclose.

References

1. Prinzing A, Herold U, Berkefeld A, Krane M, Lange R, Voss B. Left ventricular assist devices—current state and perspectives. J Thorac Dis 2016;8(8):E660-6.
2. Pozzi M, Giraud R, Tozzi P, Bendjelid K, Robin J, Meyer P, et al. Lont-term continuous-flow left ventricular assist devices (LVAD) as bridge to heart transplantation. J Thorac Dis 2015;7(3):532-42.
3. Jakovljevic DG, Yacoub MH, Schueler S, MacGowan GA, Velicki L, Seferovic PM, et al. Left ventricular assist device as a bridge to recovery for patients with advanced heart failure. JACC 2017;69(15):1924-33.
4. Health Quality Ontario. Left ventricular assist devices for destination therapy: A health technology assessment. Ont Health Technol Assess Ser 2016;16(3):1-60.
5. Gordon RJ, Weinberg AD, Pagani FD, Slaughter MS, Pappas PS, Naka Y, et al. Prospective, multicenter study of ventricular assist device infections. Circulation 2013;127(6):691-702.
6. John R, Aaronson KD, Pae WE, Acker MA, Hathaway DR, Najarian KB, et al. Drive-line infections and sepsis in patients receiving the HVAD system as a left ventricular assist device. J Heart Lung Transplant 2014;33(10):1066-73.
7. Hannan MM, Husain S, Mattner F, Danziger-Isakov L, Drew RJ, Corey GR, et al. Working formulation for the standardization of definitions of infections in patients using ventricular assist devices. J Heart Lung Transplant 2011;30(4):375-84.
8. Nielsen JC, Gerdes JC, Varma N. Infected cardiac-implantable electronic devices: Prevention, diagnosis, and treatment. Eur Heart J 2015;36:2484-90.
9. Gomez CK, Schiffmann SR, Hobbs SK. The role of computed tomography in oredicting left ventricular assist device infectious complications. J Clin Imaging Sci 2016;6:43.
10. Litzler PY, Manrique A, Etienne M, Salles A, Edet-Sanson A, Vera P, et al. Leukocyte SPECT/CT for detecting infection of left-ventricular-assist devices: Preliminary results. J Nucl Med 2010;51:1044-8.
11. Dell'Aquila AM, Mastrobuoni S, Alles S, Wenning C, Henryk W, Schneider SRB, et al. Contributory role of fluorine 18-fluorodeoxyglucose positron emission tomography/computed tomography in the diagnosis and clinical management of infections in patients supported with a continuous-flow left ventricular assist device. Ann Thorac Surg 2016;101(1):87-94.
12. Kim J, Feller ED, Chen W, Dilsizian V. FDG PET/CT imaging for LVAD associated infections. JACC Cardiovasc Imaging 2014;7(8):839-42.
13. Tlili G, Picard F, Pinaquy JB, Domingues-Dos-Santos P, Bordenave L. The usefulness of FDG PETCT imaging in suspicion of LVAD infection. J Nucl Cardiol 2014;21(4):845-8.
14. Sarrazin JF, Philippon F, Tessier M, Guimond J, Molin F, Champagne J, et al. Usefulness of fluorine-18 Positron emission tomography/computed tomography for identification of cardiovascular implantable electronic device infections. JACC 2012;59(18):1616-25.
15. Grosman-Rimon L, Jacobs I, Tumiati LC, McDonald MA, Pollock Bar-Ziv S, Fuks A, et al. Longitudinal assessment of inflammation in recipients of continuous-flow left ventricular assist devices. Can J Cardiol 2015;31:348-56.